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DEPARTMENT OF CHEMICAL ENGINEERING AND CHEMICAL TECHNOLOGY

IMPERIAL COLLEGE

"Laser Initiated Ignition of Liquid Propellant"

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5TH INTERIM REPORT

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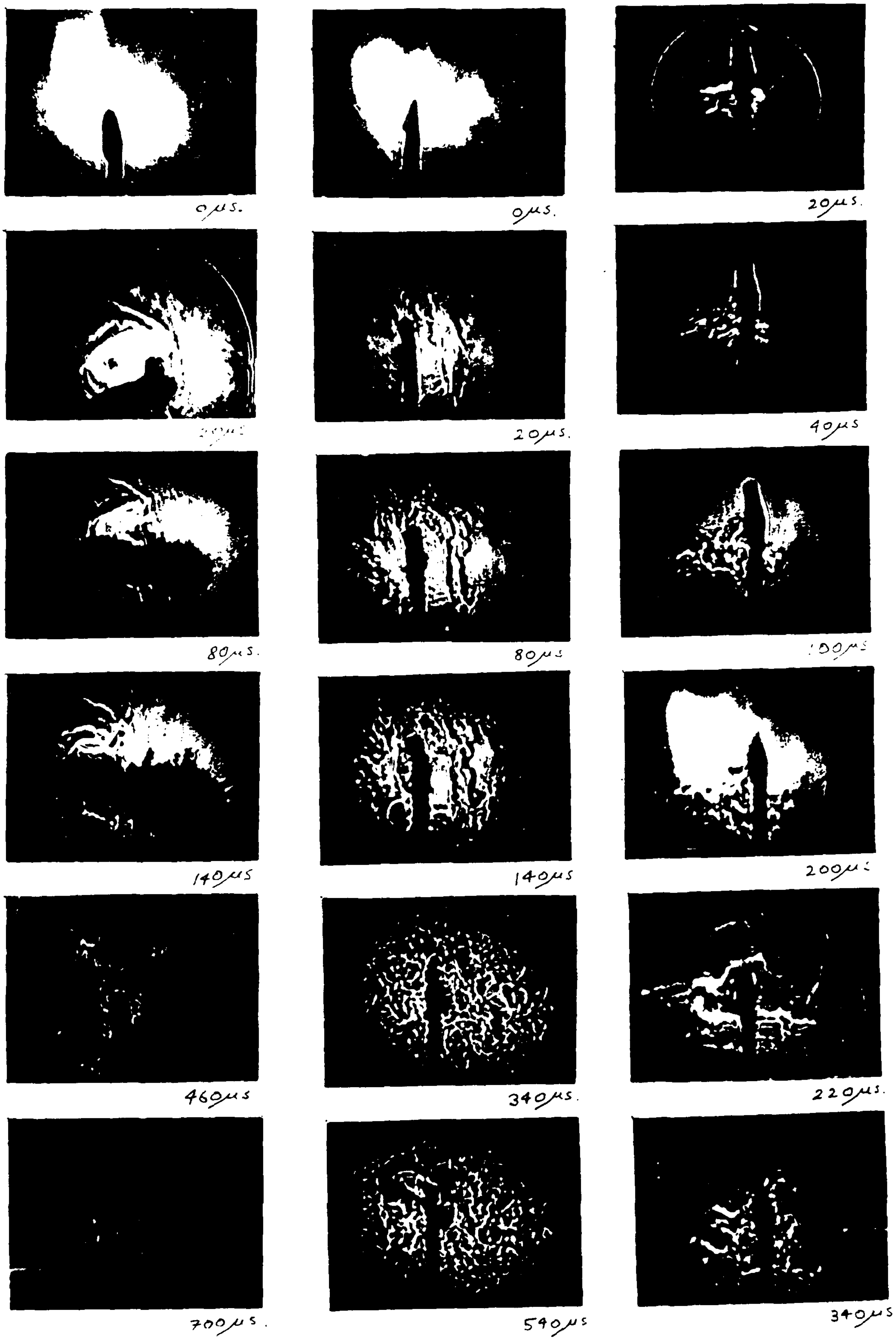
Laser Ignition of Large Droplets

The 4th Interim Report included the first high speed movie sequence, albeit of rather poor optical quality, of the interaction between laser generated plasma and a droplet. This was a first step in a more extensive series of studies. Figure 1 shows three sequences illustrating the various parameters under investigation. These include the energy of the laser beam and the distance between the position of the laser focus and the droplet. Moreover, double firing the laser can be used to inject a second plasma kernel into the environment of a drop that is already disintegrating.

The records show interaction with the propellant droplet of a rapidly expanding shock wave as well as the more slowly developing plasma kernel and illustrate the wide variation in the rate and completeness of the burning of the droplet that can be achieved. The provisional interpretation is that the shock wave emanating from the laser-generated plasma shatters the droplet and the fine filaments of liquid propellant which result are ignited when they become engulfed by the plasma. This makes the intensity of burning very dependent on the relative positioning of the droplet and laser focus. A second laser pulse (e.g. 200μs, 3rd sequence) interacting with the disintegrating and burning fragments from the first is an additional means of promoting rapid decomposition. Comparative experiments with water droplets show shattering without combustion.

"Electrostatic" Spraying of Propellant

Since it appears that the laser-induced plasma interacts with a spray of propellant, it seemed sensible to explore interaction with a pre-formed mist. This was to be generated by spraying from a fine capillary in a large (kilovolts per centimeter) divergent electric field, because this method of atomisation uniquely allows minute quantities of liquid to be sprayed without the use of a second


0µs.
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200µs
460µs
340µs.
220µs.
700µs.
540µs
340µs.

atomising fluid. The method has been shown feasible in principle several years ago as a result of a proposal made by one us (FJW) for experiments carried out by Mr. John Knapton at BRL.

A simple preliminary experiment was set up to allow us to determine the conditions (equipment geometry and field strength) under which electrostatic spraying of the propellant could be achieved in the form of a fan of very small droplets. No confinement was used, in order to minimise the risk of an accidental detonation.

The most successful geometry is shown in Figure 2. In this the negative electrode is a wire ring, of 18mm diameter. The propellant is contained in a miniature glass funnel ending in a capillary. A wire is immersed in the propellant in the funnel and is connected to high voltage power supply via a chain of 30 resistors, each one of 8.2 Mohms. The power supply can give a low continuously adjustable current output over the range 1-30 kV. The negative electrode, the case of the power supply and the negative output connection of the power supply are connected and earthed. Under these conditions, the best spraying shape and density was achieved at a voltage of 15kV.

Experiments with saturated salt solution in place of the propellant were not as successful. It seems that the combination of surface tension viscosity and density of the propellant are well suited for this form of spraying.

After stable electrostatic spraying conditions were established, the beam of a ruby laser was focused in the area of the immediate vicinity of a quantity of propellant.

Although the possibility of a detonation of the cloud of the propellant

droplets seems remote, safety measures were taken in order to protect the

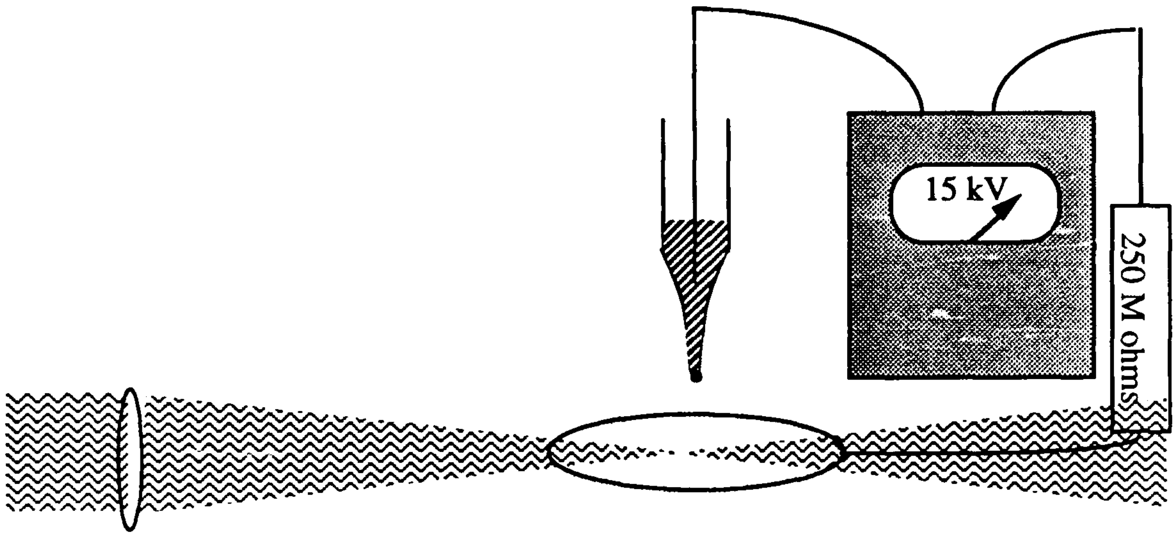

Fig. 2. E. S. Spraying of propellant in laser beam

experimenter against this unlikely event. The quantity of propellant in the capillary was limited to 30 μl, which is capable of releasing up to a maximum of only 50 J of energy in the case of the detonation. In addition, the person who operates the camera is shielded by a perspex screen 2m high and 1.2m wide. Care is also taken not to have any quantities of energetic materials in the vicinity of the experiment.

The initiating laser and optical system is identical to that previously used for focusing the laser beam on a droplet. The only addition is the power supply for the spraying electrostatic field, which is not synchronised with any other components. Early trials reveal no audible effects or smoke, which is not unreasonable, taking into acount the very small quantity of propellant present near the focus of the laser beam.

Plasma Jets and Sprays

The interaction of gaseous plasma with a spray of propellant may prove particularly apposite to the gun ignition problem. So far, much more attention

has been devoted to ignition within a plasma plug than to the crucial next stage - the transmission of combustion to the main charge. It is not entirely clear even whether we should be concentrating on ignition of the spray or of a continuous body of liquid. Even in the latter case, the flame propagation process is likely to produce droplets.

Accordingly we turned to the study of pulsed gaseous plasma jets interacting with liquid propellant spray. The pulsed plasma plugs for gaesous feedstocks are similar in design to the plugs used for liquid propellants. The particular design used in this investigation was a modified surface discharge plug which incorporated a fine capillary, permitting various gaseous feedstocks to be supplied to the cavity during the discharge sequence. A short cylinder of mild steel, in which the cavity and orifice have been drilled, surrounds the concentric electrode arrangement.

The power supply for pulsed gaseous plasma jets differs from that used for the conducting liquid propellants. In the latter, electrical energy is delivered to the plug from the storage capacitors when an intervening thryristor is switched on by means of a small electrical pulse. Initially, both electrodes are isolated from the storage capacitors and are at zero electrical potential since the liquid propellant forms a conducting path to the earth electrode. The subsequent dumping of electrical energy can only occur if the liquid propellant and the accompanying plasma cause a short circuit to earth. The thyristor becomes an electrically open circuit when the current through the plug falls to zero.

In pulsed gaseous plasma plugs, the gaseous medium between the electrodes of the plug does not form a conducting path and it is possible to establish an electrical potential on one electrode without causing electrical breakdown in the intervening gap. A separate power supply was modified accordingly. An

electronic ignition system and high performance car ignition coil provide an initiating spark fed to the plasma plug through a secondary spark gap. An induction coil between the storage capacitors and the secondary spark gap directs the A.C. spark to the electrodes of the plasma plug, causing breakdown in resistance between the electrodes. The storage capacitors are now short circuited to earth through the earth electrode of the plasma plug.

Air plasmas from such plugs have been fired across the spray, with little immediate evidence of additional energy release. Optical studies are held up by electromagnetic interference with the laser by the plasma jet.

Next Steps

Following the excursion into spray initiation, measurements on single droplets are to be resumed with the aim of ascertaining the role of "Event 1" and the role of oxides of nitrogen. To this end, suspension of the droplet between two wire loops is to be resumed and the effect of precursory electrolysis on the initiation of the droplet by laser pulse is to be investigated. Also, since it has been suggested that the success of the previous experiments may have been due to NO formed in the laser-induced air plasma, the experiment is to be repeated in an inert atmosphere. Were this indeed to show that no propellant decomposition occurs under these conditions, the effect of artificially enhancing NO in the vicinity of the droplet would be studied. The energy and volume of gas released by propellant decomposition is to be monitored, as previously discussed, by measuring the volumetric expansion.